Abstract Title Page
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Title: Deconstructing the Instruction of the Control of Variables Strategy: Key Components of Science Instruction

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Abstract Body

Limit 4 pages single spaced.

Background / Context:

Description of prior research and its intellectual context.

A crucial element of the logic of the scientific method is the Control of Variables Strategy (CVS), in which conclusions about causal relations are enabled by manipulating a focal variable of interest while holding all other variables constant. Understanding CVS in elementary grades generally is poor, but can be improved with systematic instruction. Chen and Klahr (1999) developed a brief teaching intervention combining direct instruction in CVS with hands-on experience in constructing experiments. The method has been shown to be effective in individual instruction and in classroom settings (Klahr & Nigam, 2004; Lorch et al., 2010). Although relatively brief, the intervention is sufficiently complex that questions remain concerning which of its components are critical to success. Further, the intervention is effective in classrooms that are relatively high-achieving in science, but less effective in lower-achieving classrooms (Lorch et al., 2010). In our program of research, we have “deconstructed” the teaching intervention to determine its most important components and to examine strategies for improving learning for all students.

Purpose / Objective / Research Question / Focus of Study:

Description of the focus of the research.

The studies to be discussed in this presentation center on two questions: What components of the Chen and Klahr (1999) teaching intervention are most important in producing and maintaining children’s understanding of CVS? How can we build from this knowledge to improve understanding of CVS for all students?

Setting:

Description of the research location.

The studies discussed in the symposium all were conducted in public elementary schools. Some examined classroom-based interventions that were delivered as part of regular instruction in 4^{th} grade classrooms of 20-28 students. Other studies involved individual sessions with 3^{rd} or 4^{th} grade students, either during the school day or as part of an after-school program.

Population / Participants / Subjects:

Description of the participants in the study: who, how many, key features, or characteristics.

Classroom-based studies were conducted with 4^{th} grade children from 96 classrooms in public elementary schools. Schools were selected to represent high average (schools that achieved highest scores in the district) or low average (schools that achieved the lowest scores in the district) scores on a statewide standardized test of science achievement. Studies involving individual sessions sampled 3^{rd} or 4^{th} grade students (who had not participated in classroom-based studies) from these and other local elementary schools. Across studies discussed in this presentation, nearly 3000 children participated.

Intervention / Program / Practice:

Description of the intervention, program, or practice, including details of administration and duration. For Track 2, this may include the development and validation of a measurement instrument.

Because multiple studies are discussed, the "typical" version of the intervention is described here, with variations relevant to specific research questions explained in the Research Design section. For all students, instruction centered on an example experimental situation, in which students could test whether a specific variable influenced how far a ball rolled from an inclined plane (ramp). The variables that could be manipulated included the (1) Steepness of the ramp (high or low); (2) Surface of the ramp (rough or smooth); (3) Length of the ball's run (long or short, determined by the starting point); Type of ball (in some studies new or used; in other studies large or small). On Day 1 of a classroom-based study or in the first part of an individual session, students completed a pretest of the ability to identify valid experiments (binary-choice test), then were introduced to the ramps variables and completed a pretest of the ability to design valid experiments (ramps design test). On Day 2 of a classroom-based study or in the second part of an individual session, students received CVS instruction appropriate to the experimental conditions of a given study. In the typical version of the instructional intervention, children first are shown examples of confounded designs. Instruction focuses on getting children to identify problems with making conclusions based on a confounded design, then led through correction of the design to create an unconfounded experiment. After working through a couple of these examples, the instructor summarizes a general principle for CVS. On Day 3 of a classroom-based study or in the last part of an individual session, children complete posttests of CVS understanding. In a subset of studies, children are tested again after a delay of 4 months to 2½ years.

Research Design:

Description of the research design.

The four studies to be presented examined the effects of specific components of CVS instruction, whether specific components varied in effects for students from schools with high average science achievement scores and students from schools with low average science achievement scores, and how components of instruction influenced maintenance of learning after delays of months or years. **Study 1** was a classroom-based experiment that examined the separate contributions of guided instruction and hands-on experimentation to learning CVS and whether these effects differ by school science achievement level. The intervention was modified to create three instructional conditions: 1) CVS instruction with no experience designing ramps, 2) no CVS instruction but students were given experience designing ramps experiments, and 3) CVS instruction and students were given experience designing ramps experiments. **Study 2** modified the third condition of Study 1 to examine, in an individual setting, the degree to which the instructor's elicitation of student responses influenced learning, as compared to a condition in which the instructor delivered the same information without asking for student responses. **Study 3** was a large-scale classroom-based study that examined the effect of the type of examples used by the teacher during CVS instruction; the order in which instruction, ramps design experience, and testing were provided; whether the effects of the type of instructional examples differed by school science achievement level; and whether learning was maintained during delays of several months or 2.5 years. In the "negative" examples condition, instruction began as described earlier, by presenting fully confounded experiments that the instructor and child corrected ("negative" examples). In the "positive" examples condition, the instructor taught CVS by presenting only unconfounded experiments and showing how these designs captured the principle of the CVS. In the "control" condition, children designed ramps experiments and completed binary-choice tests (posttests for the other conditions) before receiving CVS instruction, half with "negative" and half with "positive" examples, on Day 3. Delayed testing occurred after 4-5 months and after 2.5 years. Finally, **Study 4** investigated whether the number of variables demonstrated during one-on-one CVS instruction (4 variables vs. 2 variables) or the opportunity to plan designs in advance would influence learning of children from schools scoring low in average science achievement. Children who planned designs in advance were provided with a packet that could function to organize the design prior to building their ramps experiments. The children decided how to design their ramps on paper first and then built their ramps to match their design as they had recorded in the packet.

Data Collection and Analysis:
Description of the methods for collecting and analyzing data.
For Track 2, this may include the use of existing datasets.

As noted above, children generally completed two forms of pretests and two forms of posttests. One form of testing asked students to discriminate valid from invalid experiments (binary-choice test) and was scored in terms of the percentage of correct answers and whether the child demonstrated mastery of CVS (above 85% correct). The other tested the ability to design valid experiments (ramps design test) and was scored in terms of the percentage of test designs that were entirely correct (appropriate pairings on all 4 variables). Children who demonstrated mastery of CVS during pretesting were excluded from analyses. Children retained in the analyses averaged chance level performance on the pretests (e.g., 50% correct on binary-choice tests). Data obtained from classroom-based studies were analyzed with HLM to account for the nested structure of students within classrooms within schools. Data obtained from individual sessions were analyzed with analyses of variance.

Findings / Results:
Description of the main findings with specific details.

For simplicity, the findings presented for each study are in terms of percentage of correct answers on the binary-choice test of CVS understanding. Consistent findings emerge for the other measures noted above.

Study 1: Conditions defined by the presence of guided instruction and/or the opportunity to design ramps experiments. Learning across the three instructional conditions was ordered: guided instruction with opportunity to design ramps (72% correct) > guided instruction only (65%) > opportunity to design ramps only (57%). Although children from schools with high average science achievement scores demonstrated more learning than children from low average science achievement scores (e.g., 82% correct (high) and 63% correct (low) for guided instruction with opportunity to design ramps), the pattern of results across conditions was the same for both school environments. Differences in CVS understanding across conditions remained several months later, with little change in performance after delay.

Study 2: Role of interaction during instruction. Learning was greater in the instructional condition that included interaction (80% correct) than in the one where the same information was delivered by the instructor without eliciting student interaction, even though the individual situation ensured student attention in both conditions (70% correct).

Study 3: Instruction with "negative" examples corrected during the lesson vs. instruction centering on "positive" unconfounded designs only; instruction before or after work with ramps and testing. As in Study 1, children from schools with higher average science achievement scores learned more than those from lower average science achievement scores. More importantly, the pattern of results differed for the two school environments. Children from schools with higher average science achievement scores demonstrated greater immediate (Day 3) learning (84% correct) when presented with "negative" (confounded) examples and guided to correct the designs than when presented with "positive" (unconfounded) examples only (73% correct). However, differences between the conditions were not present after several months or after 2-1/2 years. Children from schools with lower average science achievement scores also showed better learning from the "negative" examples condition than from the "positive examples" condition at immediate testing (69% correct compared to 56% correct) and this difference remained after several months and after 2-1/2 years. Providing CVS instruction after the opportunity to design ramps and complete initial testing (at the end of Day 3 for the "control" condition) resulted in less learning than the "negative examples" and "positive examples only" conditions in schools with higher average science scores and less learning than the "negative examples" condition in schools with lower average science scores.

Study 4: Effect of number of variables used in teaching and the opportunity to plan ramps designs. Learning (all in schools with low average science achievement scores) was greater when children were taught with four variables (63% correct) than when they were taught with only two variables (chance level performance of 53% correct). The opportunity to plan the design before constructing it had no effect on performance.

Conclusions:

Description of conclusions, recommendations, and limitations based on findings.

The research described here clarifies several important components that influence learning of the Control of Variables Strategy by 4^{th}-grade students. First, combining the components of teacher-led instruction and student-led manipulation benefits learning in a way that neither element alone achieves. Second, opportunities for student-teacher interaction produced more learning than instruction that did not call for student response. Third, attempts to increase learning among children from schools low in science achievement by "simplifying" CVS instruction were not successful. That is, focusing instruction on unconfounded experiments ("positive" examples in Study 3) or reducing the number of variables that students needed to attend to during instruction (Study 4) were not as effective as instruction that began with confounded experiments or required children to attend to more variables, particularly among children from schools lower in average science achievement. Both of the latter conditions may place more stress on the rationale for CVS and on why all variables other than the focal one must be controlled. Fourth, the benefits of CVS instruction are best consolidated and maintained over time when instruction precedes the student-led design of ramps experiments and CVS testing. Finally, the major challenge for future efforts to improve CVS understanding is to improve the effectiveness of instruction for children who may be less prepared for science instruction. For these children, it may be essential to place more emphasis on promoting understanding of the goal of scientific experiments prior to instruction in the manipulation and control of variables.

Appendices

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Appendix A. References

References are to be in APA version 6 format.

Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the Control of Variables Strategy. *Child Development*, *70*(5), 1098-1120.

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science*, *15*(10), 661-667.

Lorch, R. Jr., Lorch, E. P., Calderhead, W. J., Dunlap, E. E., Hodell, E. C., & Freer, B. (2010). Learning the control of variables strategy in higher and lower achieving classrooms: Contributions of explicit instruction and experimentation. *Journal of Educational Psychology*, *102*(1), 90-101.